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BULLETIN OF THE
U.S. DEPARTMENT OF AGRICULTURE

No. 135

Contribution from the Bureau of Plant Industry, Wm. A. Taylor, Chief.
September 10, 1914.

EXPERIMENTS IN THE PRODUCTION OF CROPS ON ALKALI LAND ON THE HUNTLEY RECLAMATION PROJECT, MONTANA.

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INTRODUCTION.

On the Huntley Reclamation Project in Montana there is a large area, comprising as much as 6,000 or 7,000 acres, or somewhat less than one-fourth of the area of the project, in which much of the land contains an excess of salt or alkali. There is, of course, much variation in the salt content of this land, but on all of this portion of the project there has been more or less difficulty in getting good results with crops. This salt, which is made up largely of sulphates of soda and lime, has been derived from the weathering of the underlying shale and from leaching from the shale beds which protrude from the higher lands south of the irrigated tract.

Soon after the project was opened to settlement in 1907 it became apparent that some special methods would be required to bring these salty lands into full production. In 1909 the Department of Agriculture established an experiment farm on the Huntley project near the town site of Osborn. At this point the salt content of the soil is not excessive. In order to meet the demand for information as to the best method for reclaiming the salty land, operations were begun in the autumn of 1910 on a tract of 40 acres near the town site of Worden, 4 miles east of the experiment farm. This Worden tract, as it is called, is situated near the center of the badly affected area and is fairly representative of that area.

The surface soil on this tract is a very heavy impervious clay containing alkali salts in amounts that are not tolerated by most crop plants. The physical character of the soil is such as to prevent natural leaching, and there has been an accumulation of the salts in the surface soil. Underlying the surface soil, at depths varying from 5 to 8 feet, is a stratum of sand and gravel.

The land in the affected area is somewhat lower than the surrounding lands of the project and is generally rather level, being broken only occasionally by slight depressions or natural-drainage wasteways. Very little leveling is necessary in preparing the land for irrigation.

The natural vegetation is a low, scattering growth of scrub sage and saltbush and a very little grass. Throughout the entire area are many small spots entirely barren of vegetation. The soil on these barren spots bakes rapidly and becomes very hard after rains.

The lower layers of the soil between the upper foot or two and the underlying gravel contain very little moisture before irrigation water is applied or before they are affected by the rise of ground water. The ground water at the time this work was started in 1910 was 6 to 8 feet below the surface and occurred only in the underlying gravel. This gravel stratum is apparently broken or contains so much fine material that the water entering the soil from the irrigation of higher lands can not be carried off as rapidly as it enters the soil, and there has been a consequent rise of the ground water over this area during the past two years. It rose during the season of 1913 to within about 3 feet of the surface.

It appears that the problem involved in the reclamation of this land is the opening up of the surface soil so as to make possible the leaching out of the alkali salts either by the application of irrigation water or by the rainfall.

This soil is also very deficient in vegetable matter, and it appeared that the addition of humus by plowing under green-manure crops would be one of the best means of improving the physical condition of the soil. Rye appeared to be the best crop for this purpose, as it is able to produce a crop under rather adverse conditions. In the fall of 1910 about 12 acres of the land on this tract were broken up and planted to winter rye. This land lies in two fields. Field M–I contains about 5 acres and field M–II about 7 acres. The rye crop made a fair though rather irregular growth, and was plowed under in June, 1911, when the plants were heading. On the 7-acre field and on a part of the 5-acre field this treatment was repeated in 1912. The second year's crop of rye was much heavier and more uniform than the first. Each year after plowing the rye under, the land was cultivated frequently after rains, to maintain a mulch and to prevent the crusting of the surface. By this method the tilth of the soil appeared to be much improved, and the amount of salt in the surface soil, as shown by determinations made at different dates, was greatly decreased. The land on which the green-manure treatment had been applied for two years was cropped to winter wheat in 1913. The wheat on field M–II yielded 28.7 bushels per acre and that on field M–I 35 bushels per acre. Trials of alfalfa and sugar beets were also made in 1913 on small plats that had received the green-

manure treatment. Sugar beets yielded at the rate of 11 tons per acre, and a satisfactory stand of alfalfa was secured, although the success of this crop will, of course, not be known until next season.

It appeared that the leaching out of the salts might be hastened by frequent light applications of irrigation water followed by cultivation after each irrigation. The purpose of this cultivation was to keep the soil opened and to cause the water to move downward through the soil to the underlying gravel.

This irrigation was done by means of the bordered check system in which small plats were bordered and made as nearly level as possible, so that the drying of the soil after irrigation would be uniform, in order that the cultivation would not be delayed. This method was practiced on a series of plats on which one green-manure crop had been plowed under and was continued during a part of the season of 1911 and all of the season of 1912. Determinations made at different times indicated that the total salt content of the soil was at first materially reduced by this method, but that it increased slightly in the lower depths during the latter part of 1913, owing to the rapid rise of the ground water. This land was cropped in 1913 to alfalfa and oats, one plat to each crop. A good stand of alfalfa was secured, and the oats yielded at the rate of 51.6 bushels per acre.

On another series of plats on which the flooding and cultivation treatment was practiced, manure was applied at the rate of 20 loads per acre each year during 1911 and 1912. Determinations of the total salt content of the soil indicate that this method was only slightly more effective in reducing the salt in the soil than the irrigation and cultivation treatment without the use of barnyard manure. The crops grown on this land in 1913 were spring wheat, oats, and sugar beets. Wheat yielded at the rate of 36 bushels, oats at the rate of 68.9 bushels, and beets at the rate of 7.9 tons per acre.

The method of plowing under green manure has apparently been more effective in reducing the salt content of the soil, as indicated by determinations made in 1913, than has either of the other methods tried.

During the latter part of the season of 1912 and during 1913 there has been a rapid rise of the ground water over this area. The average depth during 1913 was about 3 feet, and it is apparent that underground drainage will be required before the benefits of soil treatment can be expected to be permanent.

The experimental work, begun on this tract in 1910, has been continued during three seasons and is still in progress. While the reclamation of the tract is not yet completed, substantial progress has been made, and it seems desirable to publish an account of the

work and of the results so far accomplished. A detailed account of the observations made, the experiments conducted, and the results secured is given in the following pages.

QUANTITY AND CHARACTER OF THE SALT.

Determinations of the quantities of salts in this soil have been made with the electrolytic bridge at intervals since this work was started. The samples on which these determinations were made were taken from six different strata, as follows: The first 3 inches, 3 to 6 inches, 6 to 12 inches, 12 to 24 inches, 24 to 36 inches, and 36 to 48 inches. A general idea of the total salt content of the virgin soil can be obtained from the average of 50 samples from each depth taken on five different dates—May 2, June 5, July 16, September 3, and October 23, 1913—from 10 different places on the tract. The total salt content of the soil of each layer (expressed as a percentage of the air-dry soil) was found to be as follows: Top 3 inches, 0.65; 3 to 6 inches, 0.92; 6 to 12 inches, 1.54; average of first foot, 1.16; 12 to 24 inches, 1.83; average of top 2 feet, 1.49; 24 to 36 inches, 2.08; 36 to 48 inches, 1.79; average of top 4 feet, 1.71.

It is seen that the salt content of the virgin soil increases rapidly with the depth. The average of 1.71 per cent for the whole 4-foot layer is equal to 111.73 tons of salts per acre. This percentage is too high to permit normal growth of most field crops. Analyses have been made of the salt in the soil samples taken on May 2[1] from 10 borings. The results of the analyses (expressed as percentages of air-dry soil) of the 10 composite samples are as follows: Total salts, 1.774; CaO, 0.2374; MgO, 0.0698; NO_3, trace; Na_2O, 0.4410; HCO_3, 0.0360; SO_4, 1.2386.

This analysis indicates that the salts are chiefly a mixture of the sulphates of sodium, calcium, and magnesium, and if the results are calculated in terms of these salts they show percentages of salts in the dry soil as follows: Total solids, 1.774; Na_2SO_4, 1.0106; $CaSO_4$, 0.5758; $MgSO_4$, 0.2078.

An analysis of 16 samples of this soil made by Prof. Edmund Burke, of the Montana Agricultural Experiment Station, in 1912, gave the following percentages: Na_2SO_4, 1.1284; Na_2CO_3, 0.02848; NaCl, 0.01956. These analyses show small amounts of sodium carbonate and sodium chlorid, neither of which was found in the samples analyzed in 1913. The samples from which the analyses were made in 1912 were taken from a different part of the field and were from specially selected "bad spots." This might account for the differences found.

[1] These analyses and the analyses of ground water shown in Table I were made by Mr. J. F. Breazeale, of the Bureau of Chemistry, United States Department of Agriculture.

GROUND WATER.

For the purpose of determining the depth of ground water at different times of the year, four wells have been made on the experiment tract, and measurements were made biweekly during 1913. The results of these measurements are shown in figure 1. The average depth to ground water during 1913 was 3.14 feet. This ranged from 3.76 feet on March 6 to 2.02 feet on October 2, the most rapid rise occurring during the latter part of the irrigation season.

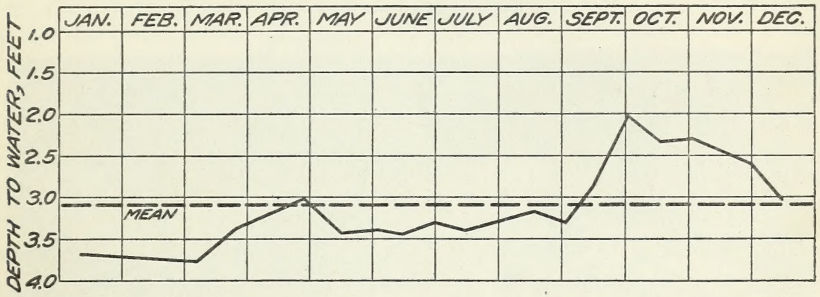

FIG. 1.—Diagram showing the depth to ground water on the Worden tract during the year 1913.

Samples of the ground water were taken from each of these wells during the season of 1913 from June to November, and nine samples from each well have been analyzed. The average results of these analyses are given in Table I.

TABLE I.—*Results of analyses of ground water from the Worden tract in 1913, showing the percentages of the substances indicated.*

Well No.	Total salts.	CaO.	MgO.	Na_2O.	CO_3.	HCO_3.	Cl.	SO_4.
A-1	1.383	0.0549	0.0719	0.437	None.	0.0277	0.0136	0.952
A-2	2.829	.0737	.1289	1.001	None.	.0381	.0294	1.901
B-1	1.512	.0178	.0521	.566	0.0026	.0169	.0109	1.027
B-2	1.165	.0193	.0268	.431	.0096	.0370	.0098	.788
Average	1.722	.0414	.0699	.609	.0030	.0299	.0159	1.167

Table I shows that the water contained an average of 1.722 per cent of total salts and that these consisted chiefly of sulphates. This amount is equal to 1.07 pounds per cubic foot of water. Analysis of the soil showed that it contained an average of 1.77 per cent of total salts. Assuming that a cubic foot of the soil weighs 75 pounds and that it contained an average of 15 pounds of water, this amount would be equal to 1.32 pounds of soluble salts per cubic foot of moist soil, or the concentration of salts in the soil water would be about 9 per cent. This concentration is about five times as great as that of the ground water.

BEHAVIOR OF CROPS ON NEWLY CULTIVATED SOIL.

Crops planted on newly broken land on the farms in this locality have been in most cases partial or total failures. Because of the refractory nature of the soil, it is generally difficult to secure a good stand. Even though a fair stand is secured, the growth of the plants is generally very irregular. (See fig. 2.) A very stunted growth, and

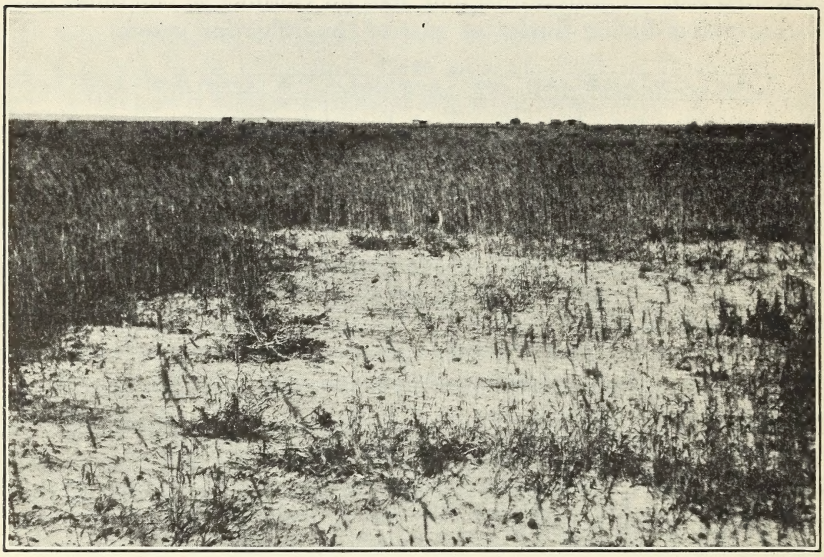

FIG. 2.—Rye in field M-I on June 21, 1911, showing the irregular growth characteristic of crops on the unreclaimed soil.

in some cases no growth at all, occurs on spots that were barren of native vegetation before the ground was broken up.

METHODS OF SOIL TREATMENT.

Three methods of soil treatment were practiced during 1911 and 1912, after plowing under the green-manure crop in 1911, on fields M-I and M-II, as shown in figure 3. Field M-I is divided into 19 plats. Plats 1 to 14, inclusive, are one-fourth of an acre and plats 15 to 19, inclusive, are one-sixth of an acre in size. Field M-II contains $6\frac{3}{4}$ acres, not divided into plats. The three methods are described as follows:

First method.—The first method was a continuation of the treatment applied in 1911. Rye was planted again in the fall of 1911 and was plowed under as green manure in June, 1912. Each season after the rye was plowed under the land was left fallow during the summer and given frequent cultivations with the disk and harrow. This method was applied on plats 1 to 12, inclusive, on field M-I and to all of field M-II. Plats 1, 2, and a part of plat 3 in field M-I were subsoiled in June, 1911. Plats 7, 8, and 9 in field M-I were planted to corn in July, 1911, but the growth was very small and irregular, and no crop was secured.

Second method.—The second method included plowing under rye as green manure in 1911, followed during the latter part of 1911 and all of the season of 1912 by frequent irrigating and cultivating. In September, 1911, the ground was leveled and bordered for irrigating in plats containing about one-sixth of an acre. Each irrigation was followed as soon as possible by cultivation. This treatment was applied on plats 15 and 16 on field M-I.

Third method.—The third method was the same as the second, except that barnyard manure was applied at the rate of 20 loads per acre in 1911 before plowing under the rye, and again in 1912. In 1912 the manure was plowed under in June and the land was immediately leveled. Alternate irrigation and cultivation was practiced during the remainder of the season. This method was applied on plats 17, 18, and 19 on field M-I.

All of the plats included in the three methods were cropped in 1913. The treatments applied in 1913 were simply the ordinary operations in the preparation of the seed bed and the subsequent irrigation and cultivation necessary in growing the different crops.

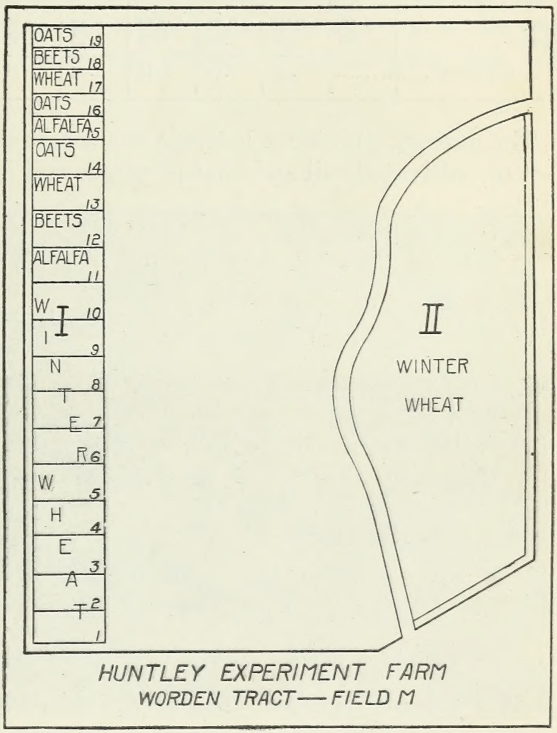

FIG. 3.—Diagram of the Worden tract, showing fields M–I and M–II, where the experiments discussed in this bulletin were carried on and indicating the location of the different crops in 1913.

RESULTS OF EXPERIMENTS.

FIRST METHOD.

Since the soil is very deficient in vegetable matter, it was thought that the addition of humus by plowing under green-manure crops would be one of the best means of opening up the surface soil. This appears to have been the case. As mentioned previously, all of the land on this tract that was broken up in 1910 was planted to winter rye and the crop plowed under in June, 1911. This treatment was repeated in 1912 on part of the land. The second rye crop made a much heavier and more uniform growth than the crop plowed under in 1911 (fig. 4), and the soil tilth appeared to be much improved.

Effect on the salt content.—Total salt determinations were made in May, June, July, September, and October, 1913, with samples taken from plats 2, 5, 7, 9, 11, and 12 in field M–I and from adjacent virgin soil.

A summary of these determinations is given in Table II, which shows the average salt content to a depth of 4 feet in 1913. The results are expressed in percentage of air-dry soil.

TABLE II.—*Average total salt content of soil to a depth of 4 feet on plats which had received treatment according to the first method and of adjacent virgin soil.*

Soil.	Number of borings.	Top 3 inches.	3 to 6 inches.	6 to 12 inches.	Average, first foot.	12 to 24 inches.	Average, top 2 feet.	24 to 36 inches.	36 to 48 inches.	Average, top 4 feet.
Cultivated	60	0.23	0.28	0.39	0.32	0.85	0.58	1.31	1.29	0.94
Virgin	50	.65	.92	1.54	1.16	1.83	1.49	2.08	1.79	1.71
Difference		.42	.64	1.15	.84	.98	.91	.77	.50	.77

The average difference between the total salt content of the first 4 feet of cultivated soil and that of virgin soil is shown by Table II to

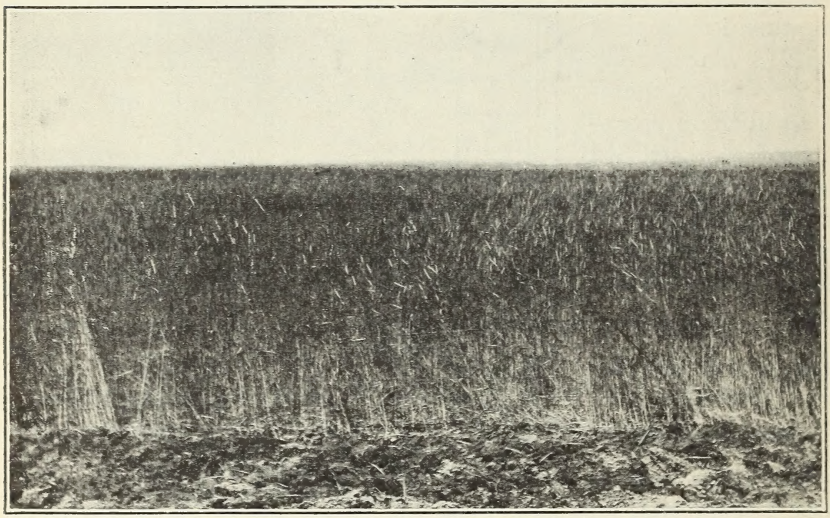

FIG. 4.—Rye in field M-II on June 13, 1912. This was the second crop of rye grown on this land and was much more uniform than the first crop.

have been 0.77 per cent. The largest differences occurred in the first and second feet. The differences are sufficient to show that the treatment given the soil has been decidedly beneficial in reducing the salt content.

It was noted that the soil of plat 2, which was subsoiled in June, 1911, contained somewhat less salt in 1913 than the plats which had not been subsoiled. The average salt content of the soil of five plats which received treatment according to the first method and which were sampled for total salt determinations in 1913 is given in Table III, together with the average salt content of the soil in plat 2.

TABLE III.—*Average total salt content of the soil on five plats not subsoiled and on a subsoiled plat, 1913.*

Plats.	Number of borings.	Top 3 inches.	3 to 6 inches.	6 to 12 inches.	Average, first foot.	12 to 24 inches.	Average, top 2 feet.	24 to 36 inches.	36 to 48 inches.	Average, top 4 feet.
Nos. 5, 7, 9, 11, and 12.	50	0.24	0.30	0.44	0.35	0.89	0.62	1.50	1.48	1.05
No. 2, subsoiled.....	10	.24	.22	.25	.24	.33	.28	.77	.79	.53
Difference.....	.....	0	.08	.19	.11	.56	.34	.73	.69	.52

The subsoiled plats showed little advantage in yield, however. The average yield of winter wheat on two plats subsoiled was at the rate of 35 bushels per acre, while the average of seven plats not subsoiled was 34.7 bushels per acre. Subsoiling is a difficult and expensive operation, and it is doubtful whether the differences in salt content, as shown above, are of sufficient importance to indicate that subsoiling would be profitable.

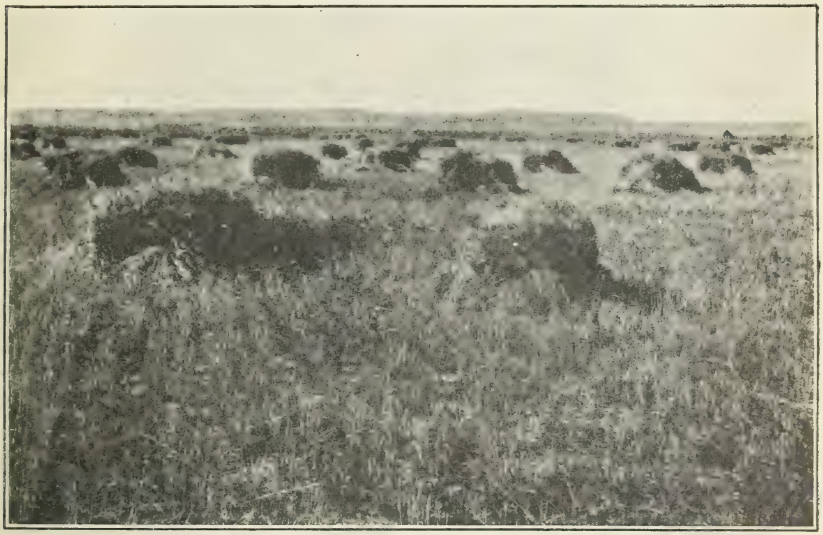

FIG. 5.—Winter wheat in field M-II on July 14, 1913. In 1911 and 1912 a crop of rye was plowed under on this field as green manure, according to the first method. The winter wheat in this field yielded 28.7 bushels per acre in 1913.

Crops grown in 1913.—Winter wheat, alfalfa, and sugar beets were grown on this land in 1913. Ten plats of winter wheat and one plat of each of the other crops were planted. At the time of planting winter wheat, in September, 1912, the ground was in excellent tilth. This crop made a much more uniform growth than the preceding crop of rye. (See fig. 5.) The alfalfa and sugar beets were planted on May 6, 1913. A good stand of alfalfa was secured and the crop was clipped on September 6. The yields of these crops are given in Table IV.

TABLE IV.—*Average yields obtained in 1913 from land treated according to the first method.*

Field.	Crop.	Area.	Variety.	Unit of yield.	Yield per acre.		
					Maximum.	Minimum.	Average.
M–I	Winter wheat	10 quarter-acre plats.	Kharkof	Bushel	41.31	29.4	34.96
M–II	do	6¾ acres	do	do			28.70
M–I	Sugar beets	1 quarter-acre plat	Kleinwanzlebener	Ton			10.97
M–I	Alfalfa	do	Montana	do			.22

While the yields are not high, they are considered very satisfactory, coming from land which had previously been unproductive. They indicate that, so far as the surface soil is concerned, the land has been fairly well reclaimed.

Cost of the method.—A record has been kept of the work done on this land from the first plowing in 1910 to the end of the season of 1912. In order to get an idea of the cost of the treatment, the different operations applied to the land have been listed and the cost of each has been estimated. The figures are given in Table V.

TABLE V.—*Estimated cost per acre of reclaiming land that received treatment according to the first method.*

Year and item of cost.	Cost.	Total.
1910.		
Breaking	$4.00	
Double disking (2 times at $1 each)	2.00	
Harrowing (2 times at 25 cents each)	.50	
Leveling	.75	
Seeding	.50	
Seed	1.20	
Total for 1910		$8.95
1911.		
Irrigating (once)	.40	
Plowing rye under	4.00	
Double disking (2 times at $1 each)	2.00	
Harrowing (3 times at 25 cents each)	.75	
Leveling	.75	
Seeding	.50	
Seed	1.20	
Total for 1911		9.60
1912.		
Plowing rye under	4.00	
Double disking (once)	1.00	
Harrowing (3 times at 25 cents each)	.75	
Total for 1912		5.75
Total for 3 years		24.30

SECOND METHOD.

The practice of alternate irrigation and cultivation was not started until September, 1911. The season was then so far advanced that it was not possible to accomplish much during the remainder of that

year. This practice was continued during the season of 1912 from May until September, the land being cultivated and irrigated at about 10-day intervals. The cultivating was done with a beet cultivator equipped with bull-tongue shovels, and the ground was leveled with a float before each irrigation.

Effect on the salt content.—Determinations, by means of the electrolytic bridge, were made of the total salts in the soil on these plats during the seasons of 1911, 1912, and 1913. Samples were taken at irregular intervals in 1911 and 1912. In 1913 complete sets of samples were taken in May, June, July, September, and October. In 1911 and 1912 samples of the following layers of soil were taken: Top 3 inches, 3 to 6 inches, 6 to 12 inches, 12 to 24 inches, and 24 to 36 inches. In 1913 samples were taken of the same layers and also of the 36 to 48 inch layer. It was found, however, that the salt content at 48 inches did not differ materially from that at 36 inches, so that only the surface 36 inches of soil are considered in the comparisons here given. Table VI shows the average salt content at specified depths in 1911, 1912, and 1913 expressed as percentages of air-dry soil.

TABLE VI.—*Average total salt content of soil to a depth of 3 feet on plats which had received treatment according to the second method in 1911, 1912, and 1913.*

Year.	Number of borings.	Top 3 inches.	3 to 6 inches.	6 to 12 inches.	Average, first foot.	12 to 24 inches.	Average, top 2 feet.	24 to 36 inches.	Average, top 3 feet.
1911	32	0.31	0.36	0.54	0.43	1.30	0.86	2.07	1.26
1912	36	.26	.33	.51	.40	.89	.64	1.68	.99
1913	40	.25	.34	.60	.44	1.01	.72	1.75	1.07

A study of Table VI shows that there was a reduction of 0.27 per cent in the average salt content of the upper 3 feet of soil from 1911 to 1912 and that there was an increase in 1913 over 1912 of 0.08 per cent. This increase occurred mainly in the second and third feet and accompanied the rise of the ground-water table during 1913.

In Table VII the average salt content to a depth of 4 feet in 1913 on these plats is compared with the average salt content of adjacent virgin soil in the same year. The samples were taken in May, June, July, September, and October, and the results are expressed in percentages of air-dry soil.

TABLE VII.—*Average total salt content of soil to a depth of 4 feet on plats which had received treatment according to the second method and of adjacent virgin soil in 1913.*

Treatment.	Number of borings.	Top 3 inches.	3 to 6 inches.	6 to 12 inches.	Average, first foot.	12 to 24 inches.	Average, top 2 feet.	24 to 36 inches.	36 to 48 inches.	Average, top 4 feet.
Second method	40	0.25	0.34	0.60	0.44	1.01	0.72	1.75	1.45	1.16
Virgin soil	50	.65	.92	1.54	1.16	1.83	1.49	2.08	1.79	1.71
Difference		.40	.58	.94	.72	.82	.77	.33	.34	.55

Table VII shows that there was in the first 4 feet an average difference of 0.55 per cent between the salt content of the cultivated soil and that of the virgin soil and that the largest differences were found in the first and second feet.

Crops grown in 1913.—In 1913 alfalfa and oats were planted on this ground, one plat to each crop. The oats yielded at the rate of 51.6 bushels per acre. (See fig. 6.) A good stand of alfalfa was secured, and this crop was clipped once, yielding at the rate of 360 pounds per acre. The success of the alfalfa planting will of course

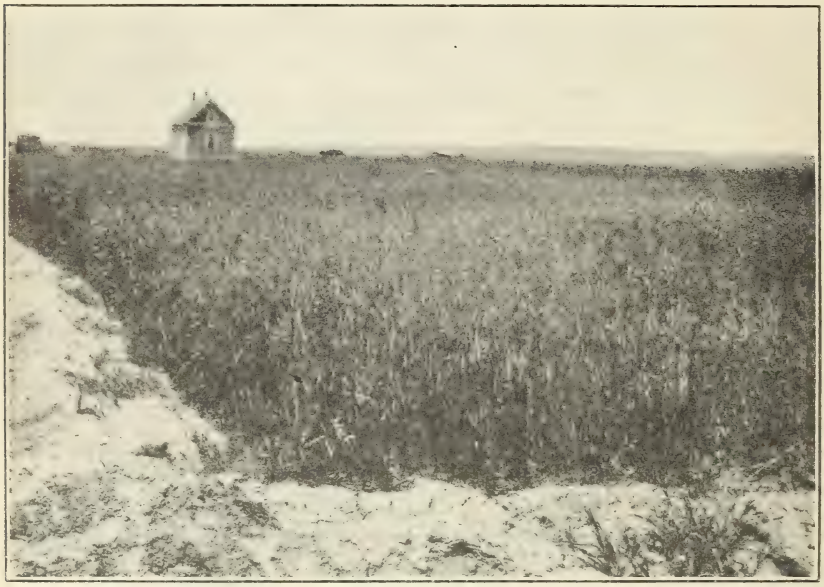

FIG. 6.—Oats on plat 16, in field M–I, on July 14, 1913. This plat received treatment according to the second method. In 1913 oats yielded at the rate of 51.56 bushels per acre.

not be known until the crop is older and the plants deeper rooted, but the fact that a good stand has been secured is an encouraging indication.

Cost of the method.—The operations applied in the second method during 1910, 1911, and 1912 are listed in Table VIII, together with the approximate cost per acre of each operation and the total approximate cost per acre for each year and for all three years.

TABLE VIII.—*Approximate cost per acre of reclaiming lands by the second method.*

Year and item of cost.	Cost.	Total.
1910.		
Breaking	$4.00	
Double disking (2 times at $1 each)	2.00	
Harrowing (2 times at 25 cents each)	.50	
Leveling	.75	
Seeding	.50	
Seed	1.20	
Total for 1910		$8.95

TABLE VIII.—*Approximate cost per acre of reclaiming lands by the second method*—Con

Year and item of cost.	Cost.	Total.
1911.		
Irrigating (once, in spring)	$0.40	
Plowing rye under	4.00	
Grading and bordering plats	4.00	
Irrigating (4 times at 40 cents each)	1.60	
Cultivating and leveling (4 times at $1.50 each)	6.00	
Total for 1911		$16.00
1912.		
Cultivating and leveling (8 times at $1.50)	12.00	
Irrigating (8 times at 40 cents)	3.20	
Total for 1912		15.20
Total for 3 years		40.15

THIRD METHOD.

In the third method the same treatment as that described in the second method, that of alternate irrigating and cultivating, was applied, and, in addition to this, manure was applied before plowing rye under at the rate of 20 loads per acre in 1911 and again in 1912. During the summer of 1912 the land was irrigated and cultivated at about 10-day intervals.

Effect on the salt content.—Determinations of the total salt content in the soil on these plats were made during 1911, 1912, and 1913. In 1911 and 1912 samples of the following layers of soil were taken at irregular intervals and at depths as follows: Top 3 inches, 3 to 6 inches, 6 to 12 inches, 12 to 24 inches, and 24 to 36 inches. In 1913 complete sets of samples were taken in May, June, July, September, and October. The 1913 samples were taken to a depth of 48 inches, but it was found that the salt content at this depth was practically the same as that at 36 inches, so that only the surface 36 inches are considered in Table IX, in which the average salt content at the specified depths in 1911, 1912, and 1913 are given, the results being expressed as percentages of the air-dry soil.

TABLE IX.—*Average total salt content of soil to a depth of 3 feet on plats which had received treatment according to the third method in 1911, 1912, and 1913.*

Year.	Number of borings.	Top 3 inches.	3 to 6 inches.	6 to 12 inches.	Average, first foot.	12 to 24 inches.	Average, top 2 feet.	24 to 36 inches.	Average, top 3 feet.
1911	28	0.34	0.43	0.59	0.48	1.28	0.88	2.28	1.35
1912	36	.24	.28	.36	.31	.68	.49	1.21	.73
1913	60	.25	.29	.43	.35	.74	.54	1.37	.82

The reduction of the average salt content in the upper 3 feet of soil on these plats from 1911 to 1912 was 0.62 per cent. There was a slight increase in 1913 over 1912. This increase occurred mainly in

the lower depths and accompanied the rise of ground water during the season of 1913.

In Table X the average salt content to a depth of 4 feet in 1913 on these plats is compared with the average salt content of the virgin soil of adjacent plats in the same year. The samples were taken in May, June, July, September, and October, and the results are expressed in percentages of air-dry soil.

TABLE X.—*Average total salt content of soil to a depth of 4 feet on cultivated plats compared with adjacent virgin soil in 1913.*

Treatment.	Number of borings.	Top 3 inches.	3 to 6 inches.	6 to 12 inches.	Average, first foot.	12 to 24 inches.	Average, top 2 feet.	24 to 36 inches.	36 to 48 inches.	Average, top 4 feet.
Cultivated	60	0.25	0.29	0.43	0.35	0.74	0.54	1.37	1.59	1.01
Virgin	50	.65	.92	1.54	1.16	1.83	1.49	2.08	1.79	1.71
Difference		.40	.63	1.11	.81	1.09	.95	.71	.20	.70

As shown by Table X, there was a difference of 0.70 per cent between the total salt content of the cultivated soil and that of the virgin soil. The greatest differences were found in the first and second feet.

Crops grown in 1913.—The crops grown on this land in 1913 were spring wheat, sugar beets, and oats, one plat being planted to each crop. The yields secured are given in Table XI.

TABLE XI.—*Yield of crops grown in 1913 on land treated according to the third method.*

Crop.	Variety.	Unit of yield.	Yield per acre.
Spring wheat	Pringle's Champion	Bushel	36.00
Sugar beets	Kleinwanzlebener	Ton	7.86
Oats	Swedish Select	Bushel	68.87

Cost of the method.—The operations applied in the third method during 1910, 1911, and 1912, together with the approximate cost per acre of each operation and the total approximate cost per acre each year and for all three years, are shown in Table XII.

TABLE XII.—*Approximate cost per acre of reclaiming land on the Worden tract by the third method.*

Year and item of cost.	Cost.	Total.
1910.		
Breaking	$4.00	
Double disking (2 times, at $1 each)	2.00	
Harrowing (2 times, at 25 cents each)	.50	
Leveling	.75	
Seeding	.50	
Seed	1.20	
Total for 1910		$8.95

TABLE XII.—*Approximate cost per acre of reclaiming land on the Worden tract by the third method*—Continued.

Year and item of cost.	Cost.	Total.
1911.		
Irrigating (once, in spring)	$0.40	
Manuring (20 loads, at 50 cents a load)	10.00	
Plowing rye under	4.00	
Grading and bordering plats	4.00	
Irrigating (2 times, at 40 cents each)	.80	
Cultivating and leveling (3 times, at $1.50)	4.50	
Total for 1911		$23.70
1912.		
Manuring (20 loads, at 50 cents a load)	10.00	
Plowing	4.00	
Double disking	1.00	
Harrowing	.25	
Leveling	.75	
Irrigating (6 times, at 40 cents)	2.40	
Cultivating and leveling (6 times, at $1.50)	9.00	
Total for 1912		27.30
Total for 3 years		59.95

COMPARISON OF THE THREE METHODS.

Effect on salt content.—In comparing the efficiency of the different methods of reclaiming this land, the effect on the amount of total

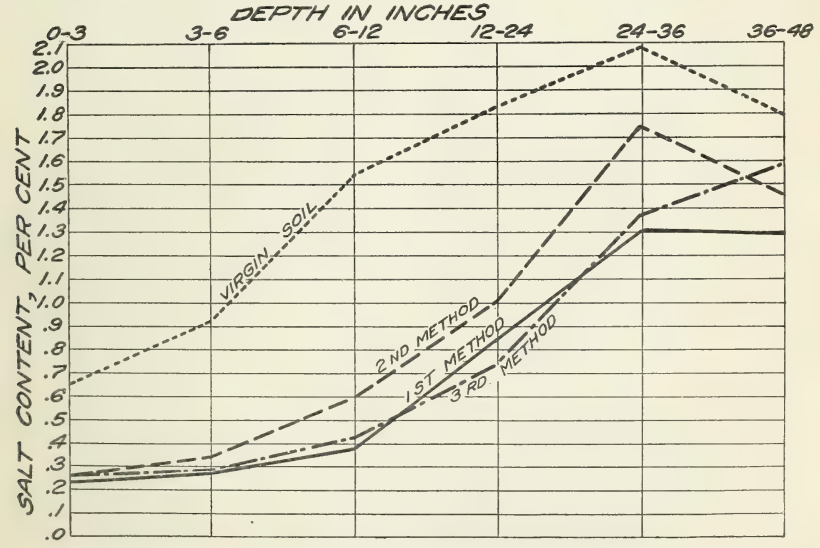

FIG. 7.—Diagram showing the average total salt content of the soil at six depths in 1913 on plats which had received treatment according to the first, second, and third methods, respectively, and of adjacent virgin soil.

salts contained in the surface 4 feet of soil will be considered first, Table XIII gives the average salt content to a depth of 4 feet in 1913, and figure 7 shows graphically the same results. These samples were taken on May 2, June 5, July 16, September 3, and October 23, 4-foot borings being made on each date.

TABLE XIII.—*Average total salt content of soil to a depth of 4 feet on plats which had received treatment according to the first, second, and third methods, respectively, and of adjacent virgin soil, in 1913.*

Soil.	Method.			Virgin soil.
	First.	Second.	Third.	
Number of borings	60	40	60	50
Layer of soil:				
Top 3 inches	0.23	0.25	0.25	0.65
3 to 6 inches	.28	.34	.29	.92
6 to 12 inches	.39	.60	.43	1.54
Average, first foot	.32	.44	.35	1.16
12 to 24 inches	.85	1.01	.74	1.83
Average, top 2 feet	.58	.72	.54	1.49
24 to 36 inches	1.31	1.75	1.37	2.08
Average, top 3 feet	.83	1.07	.82	1.69
36 to 48 inches	1.29	1.45	1.59	1.79
Average, top 4 feet	.94	1.16	1.01	1.71

From Table XIII and figure 7, it appears that the first method, that of plowing under rye as green manure and keeping the soil clean cultivated after plowing, has been the most effective in reducing the salt content of the upper 4 feet of soil. It appears also that the third method, alternate irrigating and cultivating combined with heavy applications of barnyard manure, has been second in effectiveness. This is assuming that the amount of salts was the same on all parts of the field before the ground was broken up in 1910. No determinations were made of the salt content before the ground was broken up.

Crops grown in 1913.—It is not possible to make direct comparisons of the crop returns secured in 1913 on the plats which had received different treatments in previous years. As already shown, the plats receiving the treatments according to the first method produced very satisfactory results with winter wheat, sugar beets, and alfalfa; those treated by the second method produced fair returns from oats and alfalfa; and the plats treated in accordance with the third method produced spring wheat and oats satisfactorily and a fair yield of sugar beets. The chief point to be considered in connection with the crop returns in 1913 is that the behavior of all the crops grown indicated that the soil on all the plats which have received treatment has been greatly benefited, and that so far as the surface soil is concerned the treated land has been fairly well reclaimed. Whether the reclamation is to be permanent will depend on future conditions, of which drainage is probably the most important.

Cost.—A comparison of the approximate cost per acre of the different methods is given in Table XIV.

TABLE XIV.—*Approximate cost per acre of reclaiming land according to the first, second, and third methods, respectively.*

Year and item of cost.	Method.		
	First.	Second.	Third.
1910.			
Breaking	$4.00	$4.00	$4.00
Double disking (2 times, at $1)	2.00	2.00	2.00
Harrowing (2 times, at 25 cents)	.50	.50	.50
Leveling	.75	.75	.75
Seeding	.50	.50	.50
Seed	1.20	1.20	1.20
Total for 1910	8.95	8.95	8.95
1911.			
Irrigating (once, in spring)	.40	.40	.40
Manuring (20 loads, at 50 cents a load)	.....	.....	10.00
Plowing rye under	4.00	4.00	4.00
Double disking (2 times, at $1)	2.00	.....	.....
Leveling and bordering	.....	4.00	4.00
Harrowing (3 times, at 25 cents)	.75	.....	.....
Irrigating (at 40 cents each time)	.....	1.60	.80
Cultivating and leveling (at $1.50 each time)	.....	6.00	4.50
Leveling	.75	.....	.....
Seeding	.50	.....	.....
Seed	1.20	.....	.....
Total for 1911	9.60	16.00	23.70
1912.			
Manuring (20 loads, at 50 cents a load)	.....	.....	10.00
Plowing	4.00	.....	4.00
Double disking	1.00	.....	1.00
Harrowing (at 25 cents each time)	.75	.....	.25
Leveling	.....	.....	.75
Irrigating (at 40 cents each time)	.....	3.20	2.40
Cultivating and leveling (at $1.50 each time)	.....	12.00	9.00
Total for 1912	5.75	15.20	27.30
Total for 3 years	24.30	40.15	59.95

It is shown in Table XIV that the first method was by far the least expensive of the three; that the second method, which involved a large amount of work in irrigating and cultivating, was next higher in cost; and that the third method, which differed from the second mainly in that it included an item of $20 per acre for manuring, was the most expensive of all.

SUMMARY.

(1) The surface soil on an area of approximately 7,000 acres, or about one-fourth of the Huntley project, is a heavy, impervious clay, containing alkali salts in amounts that are not tolerated by most crop plants. The total salt content of the virgin soil to a depth of 4 feet on the experiment tract averages about 1.7 per cent and consists principally of the sulphates of sodium, calcium, and magnesium.

(2) Underlying the surface soil at depths ranging from 5 to 8 feet is a stratum of sand and gravel.

(3) During 1912 and 1913 ground water has accumulated in the soil, and the ground-water level on the experiment tract has risen to

within 2 to 3 feet of the surface. This ground water contains about 1.7 per cent of salts in solution.

(4) The reclamation of the land depends on the opening up of the surface soil, so as to make possible the leaching out of the salts by the application of water, and on the drainage of the land to lower permanently the ground-water level.

(5) Experiments to determine a satisfactory method of opening up the surface soil and leaching out the salts have been conducted since 1910. Three methods have been tried:

1. Green manuring with rye, followed by the cultivation necessary to maintain a soil mulch.
2. Green manuring with rye in 1911, followed by frequent irrigation and cultivation in 1911 and throughout the season of 1912.
3. Green manuring with rye in 1911 and barnyard manuring in 1911 and 1912, combined with frequent irrigation and cultivation in 1911 and 1912.

(6) All three methods have been decidedly beneficial. The greatest reduction in the salt content resulted from the first method, the next greatest from the third method, and the least from the second method.

(7) In 1913 satisfactory crops of wheat, oats, beets, and alfalfa were produced on land which had received treatment, indicating that in so far as the surface soil is concerned the land has been fairly well reclaimed. Whether the reclamation is to be permanent will depend on future conditions, of which drainage is probably the most important.

(8) The cost of the first method was $24.30 per acre, that of the second method $40.15 per acre, and that of the third method $59.95 per acre.

(9) Considering both effectiveness and cost, the first method appears to be the best of the three.

PRACTICAL SUGGESTIONS.

Cultural directions for green manuring with rye.—Rye may be planted on this soil immediately after breaking, as was done on this tract in 1910, although it is generally difficult at first to obtain a good seed bed. It is likely that breaking earlier in the season—in June or July—and keeping the ground thoroughly cultivated with the disk and harrow after rains, would leave it in better condition at seeding time. In any case it is necessary to work the soil thoroughly with the disk and harrow before seeding. To insure a good stand it is advisable to seed rather heavily. From 1½ to 2 bushels of seed to the acre should be used. Seeding should be done, if possible, in early September, although it might be possible to secure a good stand by planting as late as October. The effect of time of seeding depends very much on the season.

In ordinary seasons irrigation will probably not be necessary. If practiced at all, it should be done so early that the ground will not be too wet for plowing at the time the crop is ready to plow under. To obtain the maximum amount of growth, plowing should be deferred until the rye is well headed, but the land should be plowed before the grain has begun to fill. Fairly deep plowing—from 7 to 10 inches—is necessary in order to cover the green-manure crop thoroughly. In plowing the crop under, a chain or rod attached to the plowbeam ahead of the plow will turn all of the rye into the furrow, so that it will be well covered. After plowing, it is advisable to disk and harrow the ground thoroughly. Cultivation during the summer after every rain of any consequence is necessary in order to prevent crusting and to keep the soil in good tilth.

Requirements for permanent reclamation.—Before any permanent benefit can be expected from any method of soil treatment it will be necessary that adequate drainage be provided in all cases where the water table has risen to within 3 or 4 feet of the surface. Where drainage systems have been installed, irrigation by means of the bordered plat system to promote leaching, together with frequent cultivation, should also prove effective in washing out the alkali salts.

The time required for reclaiming these lands will depend upon the amount of salts in the soil and the condition of the soil. It seems likely, from the results so far obtained, that treatments covering from one to three years will be necessary before satisfactory crop returns can be expected.

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